Is Cryogenically Cooled Conventional Technology a Better Value for Wireless Systems?

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Motivations

The performance enhancement of cryogenically cooling a receiver front-end for wireless applications using conventional state-of-the-art room temperature components is investigated. Conventional technologies such as LNAs and dielectrically loaded cavity filters have better performance at low temperatures due to reduced surface resistance, loss tangent and carrier mobility. Often these intrinsic properties will yield improved performance at low temperatures even if the device has been designed only with room temperature operation in mind.

Cryocoolers optimized for operation in the 120 K range have considerable advantages in one or more areas of price, reliability, and cooling capacity compared to those designed for operation at 60 K.

Cost is a very strong driving force in commercial markets. A solution which offers most of the performance advantages of its competitor at a fraction of the cost may have a strong market advantage.

Cryocooling conventional technology provides automatic continuation of service, albeit with decreased performance, in the advent of total cooler failure.

Comparison

- LNA: minimal reduction in NF from 120 K to 60 K — NF(120K) = 0.15 dB is commercially available
- Filter (dielectric loaded cavity versus HTS thin film and HTS cavity):
  - disadvantages:
    - size & weight compared to HTS thin films
    - NF and insertion loss compared to HTS (particularly cavity)
  - advantages:
    - higher power handling than HTS thin film
    - much lower intermodulation
    - temperature stability
    - IL (& NF) < 1.0 dB at room temperature (cooler failure)
- Cryocoolers (120 K):
  - disadvantages: don’t work at 60 K
  - advantages:
    - cooling capacity — can use rf coax feedthroughs with low IL
    - price
    - reliability

Cryogenic Receiver Component Technology

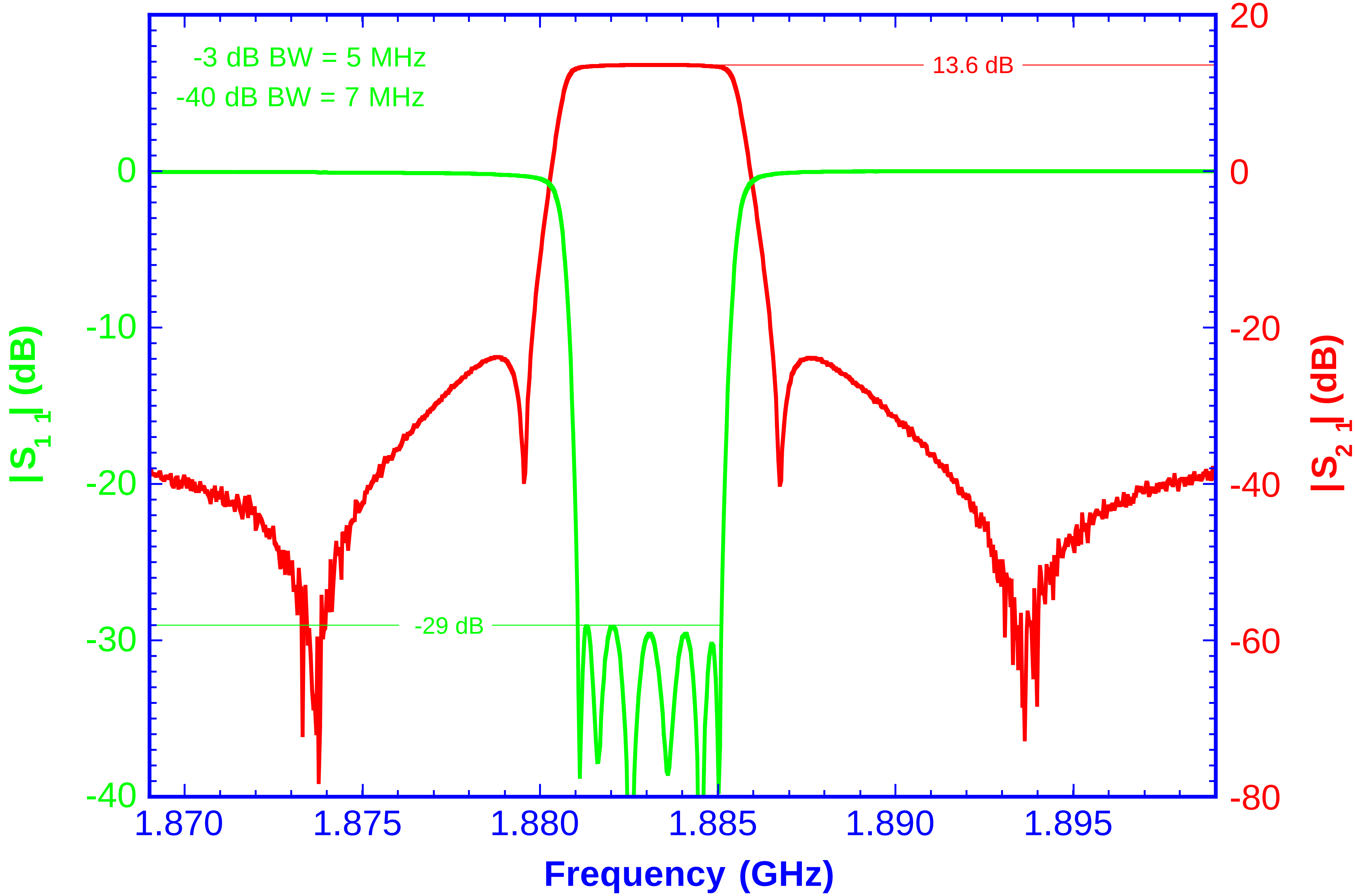
- Ceramic Loaded Waveguide TE_{01} Mode Filter with Near Ideal Symmetric or Asymmetric Elliptical Response
  - > 100 Watt power handling – suitable for Tx and Rx
  - Q_u > 30,000 @ 130 K (23,000 @ 300 K)
  - -160 dBc intermodulation for two-tone input (43 dBm)
  - IP_3 > 100 dBm
- Cryogenic Low Noise Amplifier
  - substantial development by commercial vendors (JCA, MITEQ, MWT)
  - for this demonstration: NF < 0.5 dB @ 130K (NF < 0.9 dB @ 300 K)
- CryoTiger® Cooler
  - 100,000 hour cooler MTBF
  - designed for 5 years of maintenance free operation
  - no moving parts in the cold end
  - large cooling capacity at 120 K simplifies rf feedthrough design

Measured* Noise Figures

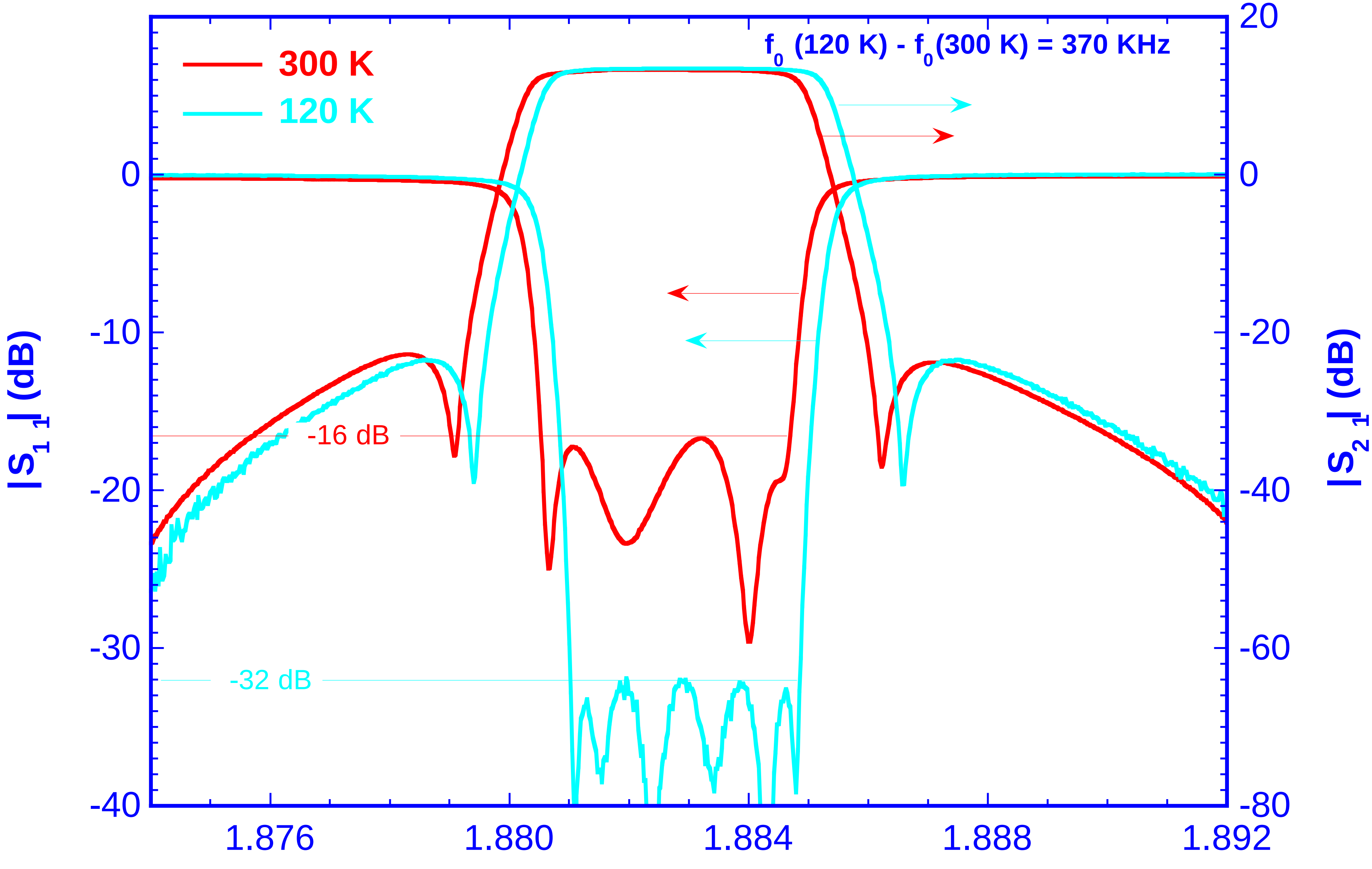
	130 K	300 K
LNA:	0.4 dB	0.75 dB
Filter:	0.25 dB	0.85 dB
Receiver:	0.7 dB	1.6 dB
Receiver in Dewar:	1.0 dB	1.9 dB

* Noise Figures were measured with an HP 8970B and 8971C Noise Figure measurement system. The measurement bandwidth of this system is on the order of the filter bandwidth and since the frequency incremented is 1 MHz an accurate measurement can not be obtained. Noise Figures of the filter are calculated from the insertion loss. Noise Figures of the receiver are calculated from the measured LNA NF and filter insertion losses. Values given for the receiver integrated in the Dewar are direct measured values and are estimated to be 0.25 dB high by direct measurement of the filter at 300 K.

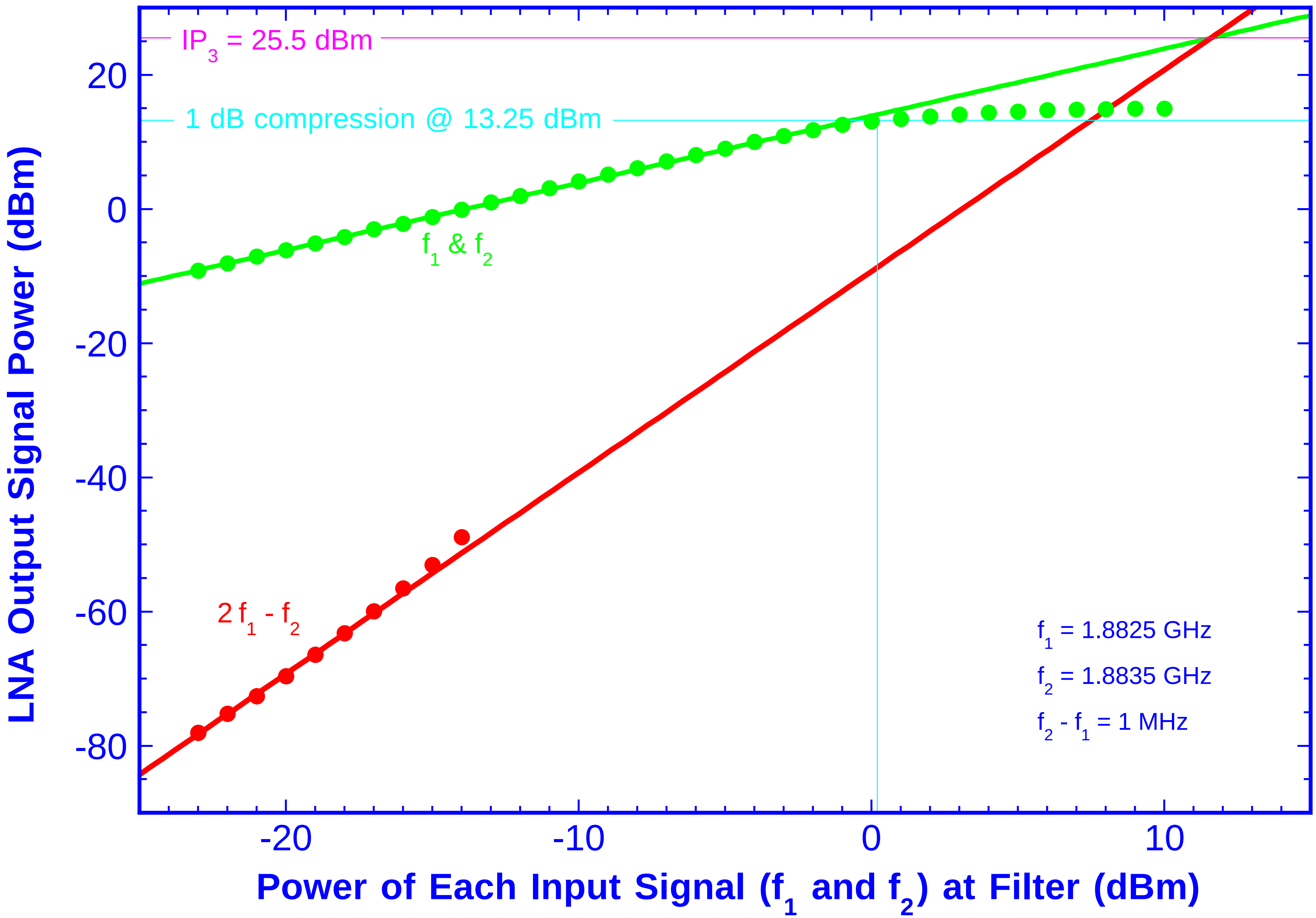
Receiver Performance at 130 K



Temperature Stability
~ 2 KHz/K



Measured IP_3 and 1 dB Compression at 130 K



Conclusions

For a small investment of time (< 1 person-year) it was demonstrated that:

- Cryogenic cooling of conventional technology results in substantial performance enhancements
- Performance approaches that of thin-film HTS wireless receiver front ends while avoiding many of the disadvantages

Substantial performance improvements can be expected given a modest investment:

- recently LNAs at 120 K with NF = 0.15 dB have become available
- Performance of ceramic dielectrics (driven by wireless market) is increasing rapidly:
  - loss tangents are decreasing — resonator Qs of 50,000 at room temperature and 100,000 at 120 K can be expected
  - higher dielectric constants will shrink filter size
  - temperature compensated design should reduce drift

Next generation design should result in receiver front-end NF ~ 0.3 dB for 5 MHz PCS band

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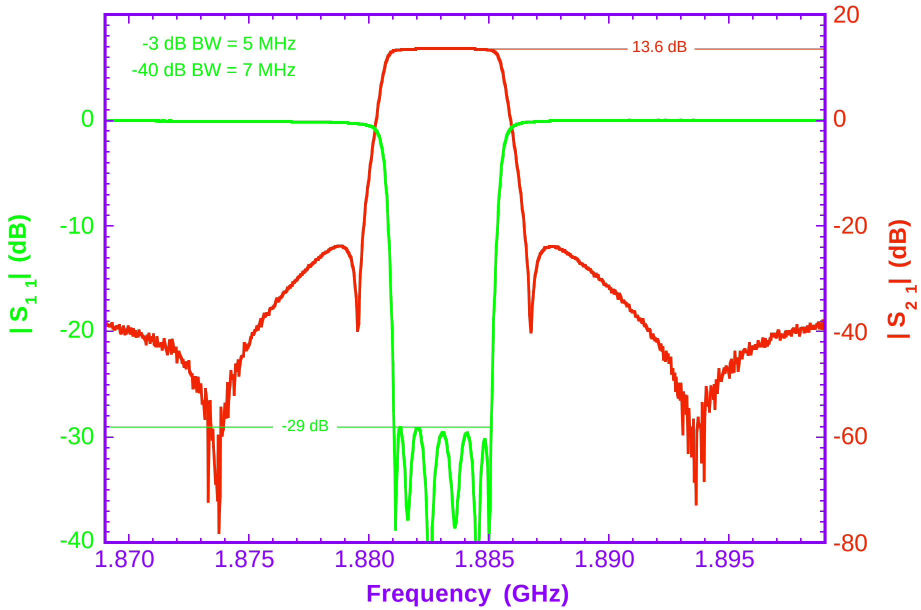

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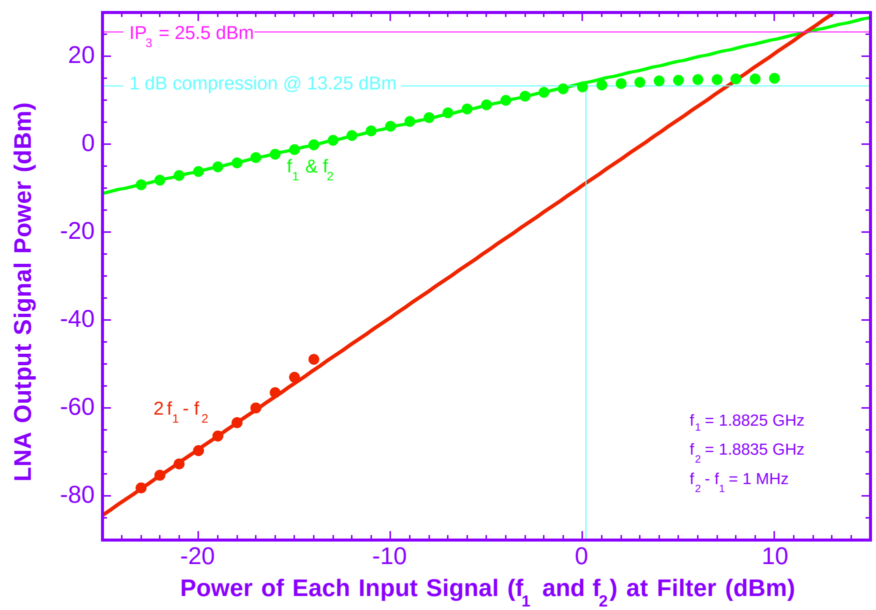

Measured Noise Figures

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Rec. in Dewar:	1.0 dB*	1.9 dB*

* Internal Noise Figure meter bandwidth limits accuracy resulting in 0.25 dB over-estimate of true NF

Conclusions

For a small investment of time it was demonstrated that:

- Cryocooling conventional technology yields marked performance enhancements
- Performance near thin-film HTS while avoiding many of the disadvantages

Substantial improvements can be expected given a modest investment:

- Recently LNAs at 120 K with NF = 0.15 dB have become available
- Performance of ceramic dielectrics (wireless market driven) is increasing rapidly
  - loss tangents decreasing
  - higher dielectric constants shrink filter size
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Next generation should yield receiver front-end NF ~ 0.3 dB for 5 MHz PCS band